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PLANETARY SCIENCE INSTITUTE

(NASA-CR-164555) PLANETARY GEOLOGICAL
STUDIES Final Report (Planetary Science
Inst., Tucson, Ariz.) 21 p HC A02/MF A01

N81-28024

CSCS 03B

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79K10377 (MOD-000) CNT#: NASW-3208 151-01-80-46-10
National Aeronautics and Space Administration, Washington, D. C. A/OSS
Planetary Science Inst., Tucson, Ariz.

L: Research in planetary geology

UNCLASSIFIED NOVEMBER 8, 1978 / NOVEMBER 7, 1979

A/DWORNIK, S. E. A/SL-4

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REPORTS EXPECTED

S: /*ASTERIODS/*CRATERS/*GEOLOGY/*IMPACT DAMAGE/*LAVA/*MARS (PLANET)/*MARS
SURFACE/*PLANETARY EVOLUTION/*PLANETS/*SOLIDIFICATION

ER:

Planetary Geological Studies

Final Report

Contract NASW-3208

Karl R. Blasius

28 February 1981

We have assembled a global data base for study of Mars crater ejecta morphology. Here we review some of the background of this work, describe some of our preliminary efforts to check the data base with findings of other workers, and layout additional investigations.

PREVIOUS STUDIES

Craters with unusual ejecta morphology were first described in detail by Carr et al. (1977) in an early publication arising from the Viking Orbiter mission, although suggestion of such features had been discussed earlier by Head (1976).

The first global inventory of crater ejecta morphology on Mars was compiled by Johansen (1978 and 1979). From an analysis of this inventory she concluded that the apparent viscosity of ejecta flows is correlated with latitude so as to suggest that variable content of liquid water and ice is responsible for morphology variations:

- a. Ejecta deposits similar to those of the Moon or Mercury (presumed, by Johansen, to be emplaced ballistically and dry) are most common near the equator ($+25^{\circ}$ latitude and very rare beyond 40° latitude.)
- b. Ejecta deposits with the lowest apparent viscosity, lobate structures with raised distal ridges, are concentrated within $+30^{\circ}$ latitude and absent beyond 60° latitude.
- c. Ejecta deposits with intermediate to high apparent viscosity, massive or multilobate structures with marginal scarps of variable slope, and sometimes having an aureole of a type (b) deposit, are most common at higher latitudes than $+30^{\circ}$.
- d. The largest diameter ejecta flows, compared to crater rim diameter, are found in the two polar regions.

Observations a. to c. are explained qualitatively by Johansen (1978) with a model of Mars having near surface liquid water and dry materials in warm equatorial regions and subsurface ice progressively thicker and nearer the surface at higher latitudes. The extremely broad ejecta deposits in polar regions are not explained.

As interesting as Johansen's results are, they cannot be taken as definitive. The study was carried out as a preliminary survey. No record was kept of the number or individual sizes and types of craters examined in each area, only the presence of one or more of six types was noted. The relative proportions of the crater types are unknown except where only one type was present. In the statements a through d. above, the latitudinal abundance of a crater type is based upon the proportion of regions examined which exhibited that crater type at any level of areal density greater than 0. The results of Johansen's study have stimulated us and others to undertake more thorough studies, documenting our data sets more completely and recording additional data on environmental parameters which might affect ejecta morphology.

Mouginis-Mark (1979) performed such a study with a global sample of 1558 martian craters. He examined the relationship of ejecta morphology to crater diameter, latitude, altitude, and target material, assigning each crater to one of six morphology types. These classes are different from those of Johansen but share many common features. Mouginis-Mark (1979) found no strong latitudinal variation in the occurrence of any class of craters, except that small craters with very extensive ejecta blankets seemed concentrated in polar regions.

The sizes of craters in the six classes of Mouginis-Mark are very different. The diameters of the polar craters with very extensive ejecta are, on average, much smaller than types of craters corresponding to Johansen's (1978) intermediate-to-high viscosity ejecta craters and those in turn seemed significantly smaller than classes corresponding to Johansen's least viscous type or her lunar/mercurian type. Mouginis-Mark also found strong correlations of crater type occurrence with geologic unit. Secondary craters seem more abundant on younger lava flows, ejecta deposits with strong radial lineations were most common on Tharsis and Elysium lavas, and the small craters with extensive ejecta blankets seemed most abundant on "fractured terrain, old lavas, and channel materials".

Having recorded both crater diameter and maximum ejecta radius for each crater, Mouginis-Mark (1979) was able to compare the mobility of ejecta with parameters such as latitude, altitude and geologic unit. He found ejecta travels farthest from crater rims at low altitudes and high latitudes. Mouginis-Mark concludes that the relationship of ejecta mobility to altitude and latitude suggests varying proportions of volatiles in the martian crust may control viscosity of ejecta. No explanation is offered for the varied morphological classes of craters except that geologic unit characteristics of some kind seemed to control some aspects of morphology.

Mouginis-Mark (1979) acknowledges that his too is a preliminary analysis of an undersized data base. He plans to expand the data set to reduce strong geographical clustering due to clustering of high resolution Viking imaging. There is a limit to such expansion, however, since enormous regions of Mars have not been photographed at better than 150m per pixel resolution, characteristic of data used for most of his analysis. A more serious issue is the selection of six crater classes used for the study. No particular arguments are offered as to why these are a more appropriate set of classes than those of Johansen (1978) for example. More consideration of crater morphology classes might turn up a system which would yield stronger correlations with latitude within the chosen set of 1558 craters.

Allen (1979) also reports a global survey of crater ejecta morphology similar to Johansen's (1978). He reports that rampart craters (apparently meaning with ejecta deposits having well-defined ridge-like terminations) occur at all latitudes, on all types of terrain, and over a wide range of altitudes. His results appear to be more consistent with those of Mouginis-Mark than those of Johansen, but the lack of information on the relative proportions of different types of craters in individual areas makes direct comparison difficult.

Other crater ejecta morphometry studies (Mouginis-Mark, 1978; Mutch and Wornow, 1980) have uncovered evidence that ejecta flows of Martian craters may have a characteristic thickness independent of crater diameter. This is a very exciting result tending to confirm the viscous flow model of ejecta emplacement first suggested by Carr, *et al.* (1977). These results were derived from samples of craters from a small fraction of the surface of Mars so they are tentative, pending confirmation from a more representative sample from varied latitudes, altitudes, and geologic units.

APPROACH

The craters studied by us were classified as to morphology using individual photographic prints of Viking Orbiter frames. Positional and scale information were derived by fitting digitized mosaic coordinates to latitude-longitude coordinates of surface features (geographic control) from the Mars geodetic control net (Davies, et al, 1978) and feature coordinates from the U.S.G.S. series of 1:5,000,000 scale shaded relief maps. The series of steps required to assemble the data base is shown in Fig. A1. The final products are a crater data base file holding a specific set of data for each crater (Table A1) and a file record of all the areas studied.

The geographic coordinates, lighting and viewing data, and scale information for each crater are derived from Viking engineering (SEDR) data describing the spacecraft location and time the images were acquired, mosaic coordinates of classified craters, and geographic control point data. A χ^2 minimization procedure was used to find an optimum perspective transformation of mosaic coordinates to Mars fixed coordinates for the geographic control points. This transformation was then used to estimate the geographic coordinates of the classified craters and the mosaic boundary points. The accuracy of this procedure is remarkably good considering that the mosaics are essentially uncontrolled. The average error in position of projected geodetic control points is just 8km or about 0.13° latitude.

Crater morphology characteristics recorded (Table A1) are of two classes - attributes of each ejecta deposit and other crater characteristics. Ejecta deposit topography at the outer margin is characterized as a distinct ridge, a simple scarp, or indistinct. The overall form of the deposit is characterized as simple (massive) or multilobate (made up of tongues of material). The surface appearance of the ejecta deposit was also characterized as to small scale topography, either rough or smooth and the presence of straight radial ridges noted.

A second set of descriptors characterize the crater floor-smooth, rough, central peak, or central pit, rim (circularity), and the presence of secondary craters.

The validity of compiling all these qualitative judgements into a data base for intercomparison is critically dependent on the choice of an image data set with fairly uniform characteristics of resolution, lighting, and viewing conditions. We also recognize that the apparent absence of some crater characteristics may be a result of actual absence or insufficient image resolution. For each crater we have stored information sufficient to derive feature dimensions in image resolution elements, so we shall be able to distinguish these two cases.

ASSEMBLY OF MARS CRATER MORPHOLOGY DATA BASE FROM MOSAICS

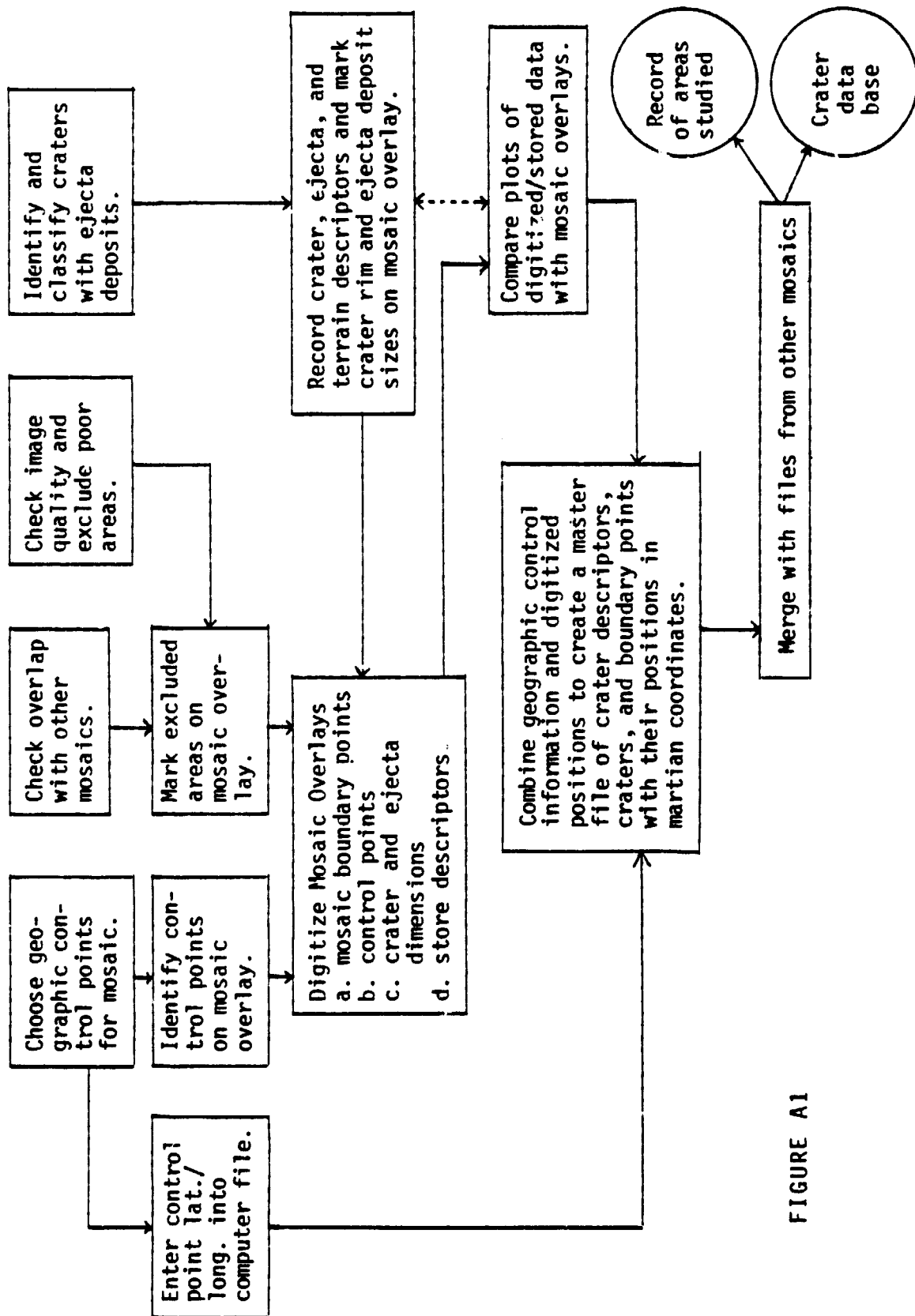


FIGURE A1

TABLE A1: CRATER EJECTA MORPHOLOGY DATA BASE

A. Image and General Crater Attributes

| ATTRIBUTE NAME | ABBR. | TYPE | RANGE | LENGTH | DESCRIPTION |
|----------------|-------|------|------------|--------|---|
| EMISSIONANGLE | EMA | REAL | 0-90 | 5 | Emission or viewing angle |
| INCIDENCEANGLE | INA | REAL | 0-90 | 5 | Incidence or lighting angle |
| PHASEANGLE | PHA | REAL | 0-180 | 6 | Phase angle |
| SCRANGE | SCRAN | REAL | 6000-20000 | 5 | Spacecraft range, km |
| LATITUDE | LAT | REAL | -90-90 | 6 | Crater latitude |
| LONGITUDE | LON | REAL | 0-360 | 6 | Crater longitude |
| LOCERR | LERR | REAL | 0-1000 | 6 | Coordinate location uncertainty, km |
| STRIPAREA | AREA | REAL | 0-107 | 10 | Area of image mosaic, km ² |
| STRIPFILE | FIL | TEXT | | 6 | Mosaic ID |
| CRATERRADIUS | R | REAL | 0-1000 | 6 | Crater radius, km |
| RADIUSFLOW1 | RF1 | REAL | 0-1000 | 6 | Radius, inner ejecta deposit, km |
| RADIUSFLOW2 | RF2 | REAL | 0-1000 | 6 | Radius, outer ejecta deposit, km |
| TERRAINDEXC1 | TD1 | TEXT | | 2 | Descriptor, first terrain type |
| TERRAINDEXC2 | TD2 | TEXT | | 2 | Descriptor, second terrain type |
| IQUAL | IQ | INT | 0-1 | 1 | Image quality (0 or 1) |
| SECONDARYC | SECC | INT | 0-1 | 1 | Secondary craters? (0 or 1) |
| CIRCULARITY | CIRC | INT | 0-1 | 1 | Circular rim? (0 or 1) |
| CENTRALFEAT | CF | INT | 0-+3 | 1 | Central feature: 3=pit, 1=rough floor, 2=smooth floor, 0=peak |
| EJECTA DEPNUM | EJDN | INT | 1-2 | 1 | Number of ejecta deposits |

B. Crater Ejecta Deposit Attributes: Each of the following represents attributes for up to four ejecta deposits on specified terrains. In each case, zero denotes the absence of an ejecta deposit "e" and "t" take on values of 1 and 2 and identify ejecta and terrain, respectively.

| | | | | | |
|---------------|--------|-----|-----|---|--------------------------------|
| MARGINTYPEet | MTYPet | INT | 0-3 | 1 | 1=indistinct, 3=scarp, 2=ridge |
| DEPOSITFORMet | DFet | INT | 0-2 | 1 | 1=multilobate, 2=simple |
| DEPSURFet | DSRFet | INT | 0-2 | 1 | 1=smooth, 2=rough |

COMPARISON WITH PREVIOUS WORK

We have analyzed some aspects of our test data set for comparison with the results of previous investigations. We have translated the classes of Johansen (1978 and 1979) and Mouginis-Mark (1979) into our data base code, Tables A2 and A3, respectively. Figure A2 shows the latitude distribution of the occurrence of four classes of craters by Johansen. In Figure A3 we show the most nearly comparable plot we could easily construct from our test data set. Johansen gives the percent of areas examined in a latitude band in which a class of craters occurs at some (nonzero) areal density. She examined craters from 2 to 25 km diameter. We show the number of craters in a class as a percent of all craters examined in a particular latitude band.

Only the occurrence of Class 2 ("Flower") craters seem to be a similar function of latitude in our two plots. Ejecta flows with terminal ridges, those with the least apparent viscosity according to Johansen, are significantly more common within 30° of the equator than at higher latitudes.

Class 2 ("Lunar") craters are present in our test data set in too small numbers to exhibit significant variations with latitude. Class 3 craters with two ejecta flow deposits each show no strong variations in either data set. Class 4 craters, having a single ejecta flow deposit with a terminal scarp, have a distribution which is a strong function of latitude in Johansen's plots, but a similar trend is only suggested by our test data set. Finally, we find 15 to 50% of our craters in each latitude bin cannot be identified with one of Johansen's four classes.

The differences between the results found with the two data sets may be due to one or more of several factors:

1. We plot types as fractions of total crater populations while Johansen only plots occurrence in sampling areas on Mars. This almost certainly accounts for our inconclusive results for Class 1.
2. Our data set does not include many 2 to 6km diameter craters; Johansen's may.
3. Our crater classification scheme allowed for classification of ejecta deposit margins as indistinct in topographic character but clearly non-lunar (not Class 1). For example, a deposit may clearly be composed of multiple flow lobes but the distal margin indistinct. We allowed also for the combination of two ejecta deposits with margin types different from Johansen's "Flower" or "Composite" classes. All but a few

TABLE A2

INTERPRETATION OF CRATER CLASSES
OF JOHANSEN (1979)

| <u>TYPE</u> | <u>OUR INTERPRETATION</u> | <u>CLASS</u> |
|---|--|--------------|
| | SECC: EJDN: (MTYPE, DF, DS, RR) _i , i = 1 to EJDN | |
| Lunar/Mercurian | [0 or 1; 1; (1,2,1 or 2, 1)] | 1 |
| Flower (lowest apparent viscosity) | [0;1 or 2; (2, 1 or 2, 1 or 2, 1 or 2)] | 2 |
| Intermediate Apparent Viscosity in order of increasing viscosity: | | |
| Composite | [0; 2; (3, 1 or 2, 1 or 2, 1 or 2); (2, 1 or 2, 1 or 2, 1 or 2)] | 3 |
| Mound or Lump | [0;1; (3, 1 or 2, 1 or 2, 1 or 2)]* | } 4 |
| Polar | [0;1; (3, 1 or 2, 1 or 2, 1 or 2)]* | |

* Johansen distinguished these two types by steepness of marginal scarps. We do not believe such qualitative distinctions can be consistently drawn with our data set of images.

percent of our "Other" craters have outer ejecta deposits with "indistinct" margin topography (Figure A4). These are not all so classified because of marginal image resolution, many of the craters are among the largest in our data set (Figure A5, A6).

We have also examined the latitudinal distributions in our sample data set of the six types of craters defined by Mouginis-Mark (1979). Figure A7 is taken from Mouginis-Mark (1979) while Figure A8 is the same type of plot of our data for six ejecta morphology classes defined to be as close as possible to those of Mouginis-Mark (Table 3). Classes 1, 2, and 6 of Mouginis-Mark's data seem to rise sufficiently above a background level of a few percent to draw some conclusions. He judged that only Class 6 exhibited significant dependence upon latitude. In our data only two of his six classes (as we interpret them) rise to similar levels. These are Classes 1 and 2. The results from our test data strongly suggest Type 1 craters are more abundant at low latitudes. We also find a large fraction of craters at all latitudes which do not fit into one of the six classes. The latitudinal distribution of Class 2 craters in our test data set shows no simple relation to latitude.

Substantial differences between our data sets may account for differences in observed trends - images chosen by us did not include a subset of high resolution images so we have fewer small craters with detailed morphology well resolved. Since the number of craters in each data set is similar we have more large diameter craters. Mouginis-Mark (1979) points out that Type 6 craters are on average his smallest class, most are less than 5 km diameter (Figure 3, Mouginis-Mark, 1979). Few such craters occur in our test data set (Figure A5).

Other reasons for relative abundance anomalies of crater types between our two data sets are illuminated by examining our class "other". This class represents 27 to 90% of the craters in each latitude interval. This class represents so many craters because the six classes defined in Table 3A do not include craters with a single ejecta flow deposit with a marginal scarp. This is Johansen's (1978) icy type (mound, lump, or polar) or Type 4 in Table 2A. Apparently, Mouginis-Mark (1979) did not distinguish this possible class of crater in setting up his six types for classification.

Alternatively, we may have misinterpreted his Type 1. Perhaps it should include single ejecta deposit craters with either marginal ridges or marginal scarps. If this is the case, Mouginis-Mark did not make a critical morphological

TABLE A3
Interpretation of Crater Classes of
Mouginis-Mark (1979)

| TYPE ID | SALIENT FEATURES | OUR INTERPRETATION [SECC; EJDN; (MTYPE, DF, DS, RF) _i , i=1, EJDN] |
|---------|--|---|
| 1 | Single ejecta deposit, marginal ridge | [0;1;(2,1 or 2,1 or 2,1)] |
| 2 | Dual ejecta deposits outer of Type 1 inner with marginal scarp | [0;2;(3,1 or 2, 1 or 2, 1) (2,1 or 2, 1 or 2,1)] |
| 3 | Multiple ejecta deposits of Type 1 | [0;2;(2,1 or 2, 1 or 2, 1) (2,1 or 2, 1 or 2,1)] |
| 4 | Radial ridges on ejecta | [0;1;(1 or 3, 2, 1 or 2, 2)] |
| 5 | Multilobate, complex secondary craters | [1;1 or 2;(1 or 2 or 3,1,1 or 2,1) X (1 or 2)] |
| 6 | Large ejecta area (pancake craters) | [0;1;(3,2,1 or 2, 1 or 2) + (RF1/R \geq 3)] |

distinction which probably prevented him from finding trends with latitude similar to those of Johansen (1978). From our test data set we have sorted out four morphological classes of craters with single ejecta flow deposits. These classes are:

1. SRS = distal ridge margin, simple structure,
2. SSS = distal scarp margin, simple structure,
3. GRM = distal ridge margin, multilobate structure
4. SSM = distal scarp margin, multilobate structure.

The distribution of Classes 1 and 3 (Figure A9) is very similar to Mouginis-Mark Type 1 (Figure A8). These craters, having ejecta deposits with marginal ridges, are more abundant at mid- and low-latitudes. Classes 2 and 4 of Figure A9 (marginal scarps) have just the opposite distribution with latitude. These tentative results are very similar in character to the findings of Johansen (1978, 1979).

We have also made a preliminary analysis of the relationship of ejecta mobility to latitude in our test data set. Figure A10 is reproduced from Mouginis-Mark (1979). He notes that the maximum distance ejecta travels from crater center, normalized to crater radius, appears to increase toward higher latitudes. In Figure A11, we plot craters binned by a similar function, mean ejecta radius/crater radius, versus latitude. Since our calculation uses mean rather than maximum ejecta radius, our mobility values are binned somewhat differently from those of Mouginis-Mark. We find the same sharp, upward trend in mobility for northern mid-to-high latitudes, but our results for the southern hemisphere are inconclusive.

CRATER STRADDLING TERRAIN BOUNDARIES

A feature of this data base which is not duplicated, to our knowledge in other crater data bases is the record of ejecta characteristics for craters straddling terrain boundaries. If the ejecta characteristics on the two terrains are different then the source of that difference can be pinpointed. As the material in the projectile that formed the crater, projectile velocity and projectile direction are common and the material that is shocked to form the ejecta deposit is likely to be similar also, only differences in the topographic character of the two terrain surfaces or the properties of the materials near the surface can account for such contrasts. In our preliminary analyses of the data sets we have found striking differences in the type of ejecta

deposit produced by craters straddling boundaries. On the rough terrain, multilobate deposit forms dominate (Table A.4) whereas on the smooth terrain the simple deposits are much more numerous. One speculative interpretation is that roughness elements on the rougher surface are responsible for splitting the flow deposit into lobes. However, much more data are needed to confirm this interpretation.

SUMMARY

These preliminary and fragmentary explorations of our growing crater morphology data base have confirmed some results of earlier studies and illuminate problems with previous classification schemes. We are confident that with our flexible classification scheme and a larger more uniform global data sample now being collected, we shall be able to clearly delineate the dependence of Martian crater ejecta morphology and morphometry on latitude, elevation, and terrain type.

Table A.2 Occurrence of Simple and Multilobate
Deposit Forms in Craters Straddling
Terrain Boundaries with Rough Terrain
on One Side and Smooth Terrain on the
Other

| <u>Terrain Type</u> | <u>Deposit Form</u> | | | |
|-------------------------|---------------------|----------|--------------------|----------|
| | <u>Simple</u> | | <u>Multilobate</u> | |
| | <u>No.</u> | <u>%</u> | <u>No.</u> | <u>%</u> |
| Rough cr. | 10 | 27.0 | 27 | 73.0 |
| Smooth cs. or cw. | 30 | 81.1 | 7 | 18.9 |

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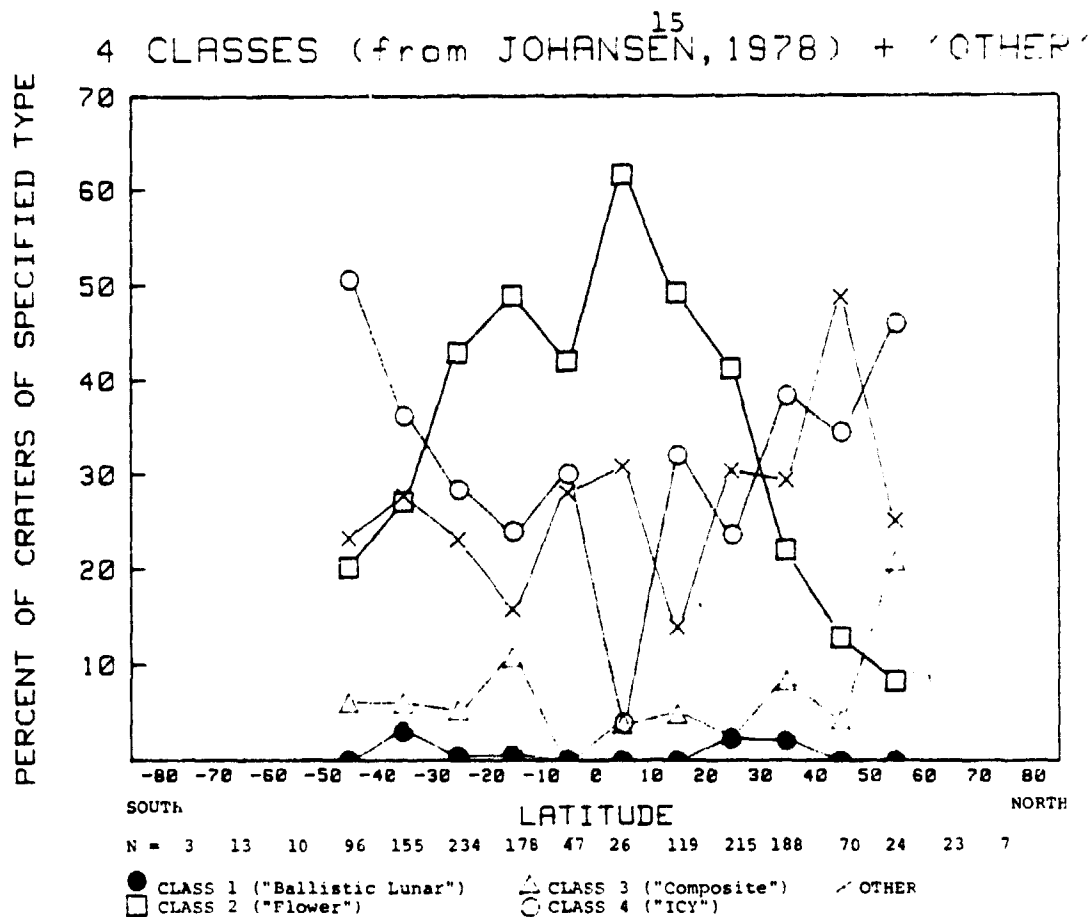


Fig. A3 Distribution with latitude in our test data set of four classes of crater ejecta morphology patterned after four types of Johnsen (see Fig. A2). Occurrence of other classes is noted.

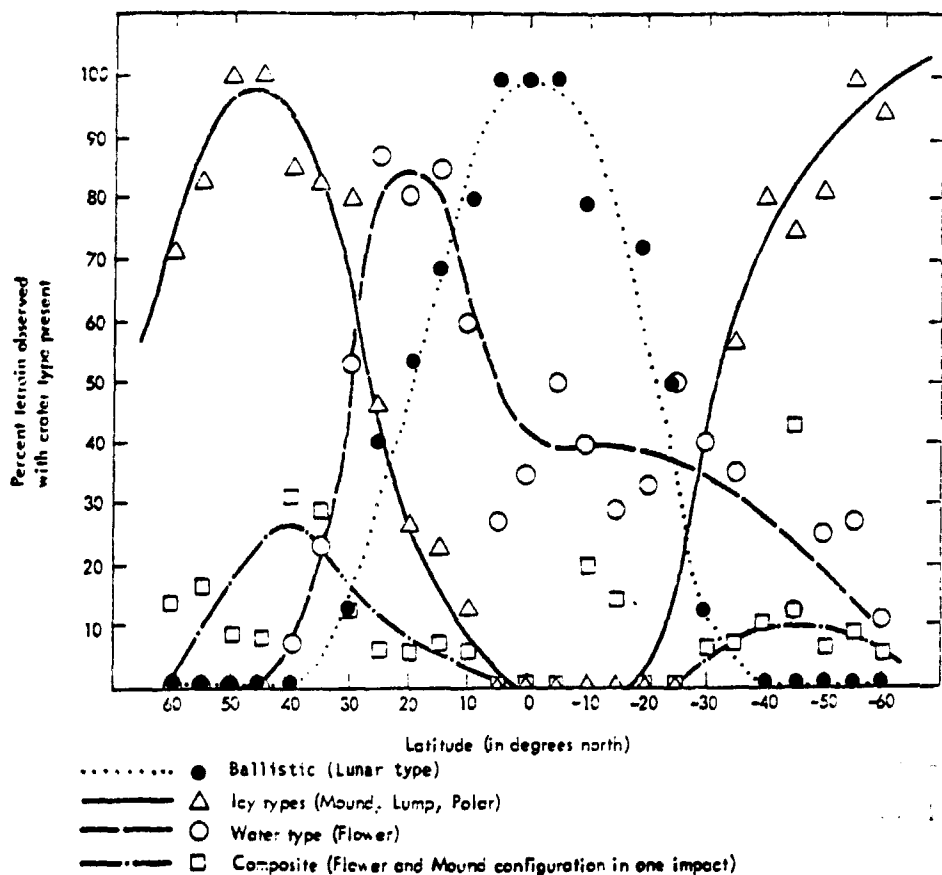


Fig. A2 Distribution of crater ejecta morphology by four

INDISTINCT OUTER MARGINS

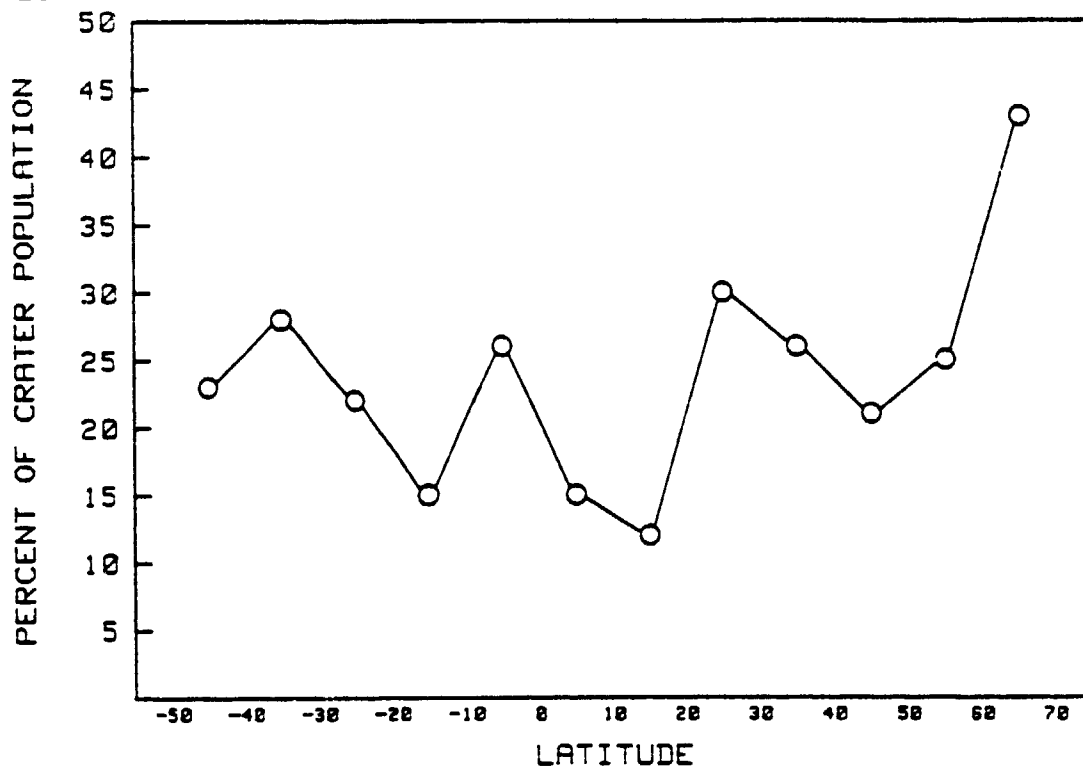


Fig. A4 Distribution with latitude of ejecta deposits with indistinct marginal topography in our test data.

DIAMETER DISTRIBUTION

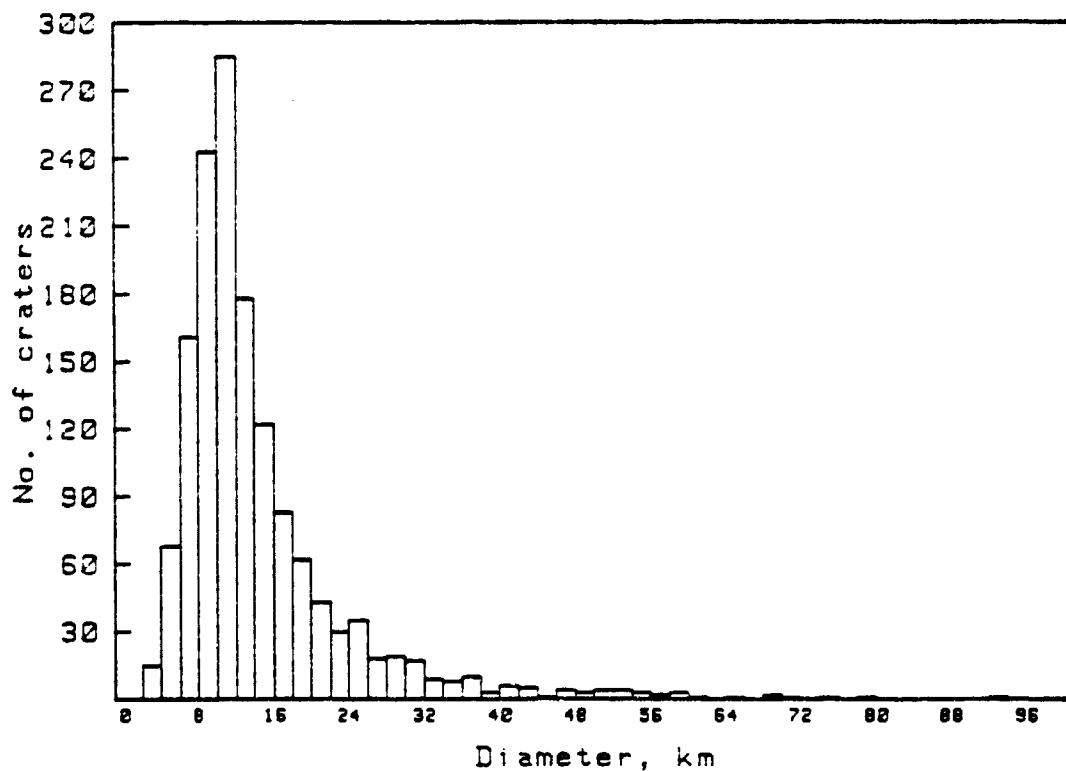


Fig. A5 Distribution over diameter of craters in our test data set.

INDISTINCT OUTER MARGINS

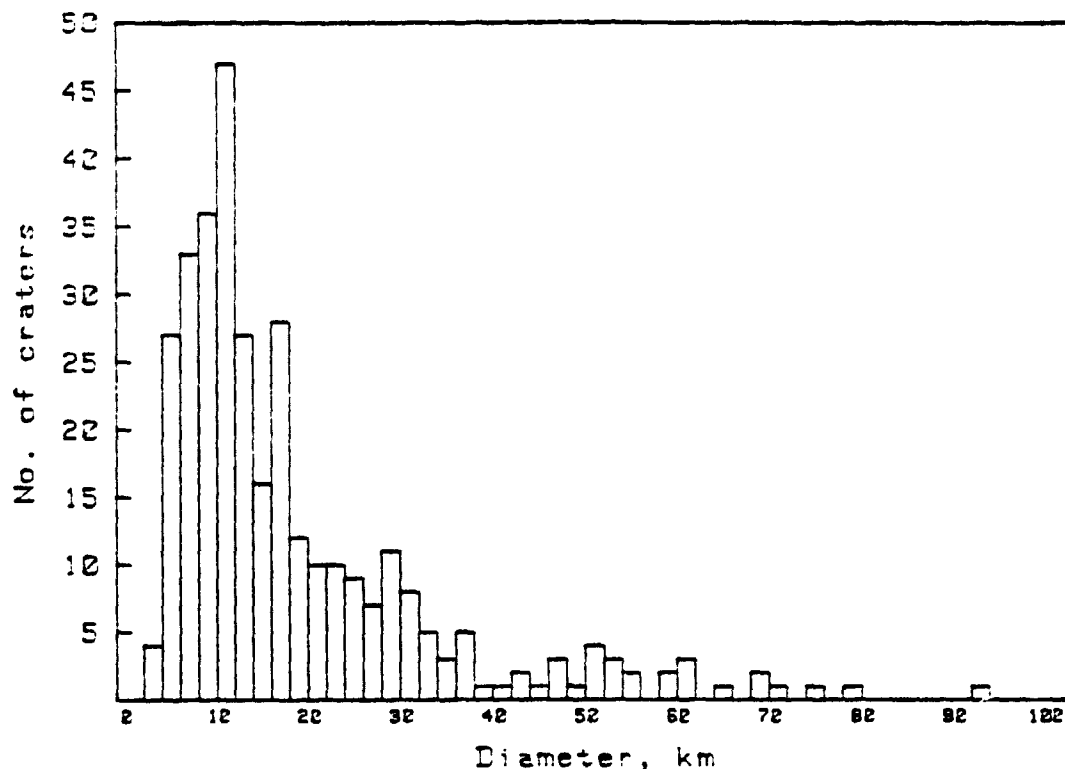


Fig. A6 Distribution of indistinct ejecta margin craters with crater diameter in our test data set. This class of crater includes virtually all large craters and a substantial fraction of intermediate size craters (compare with Fig. A5).

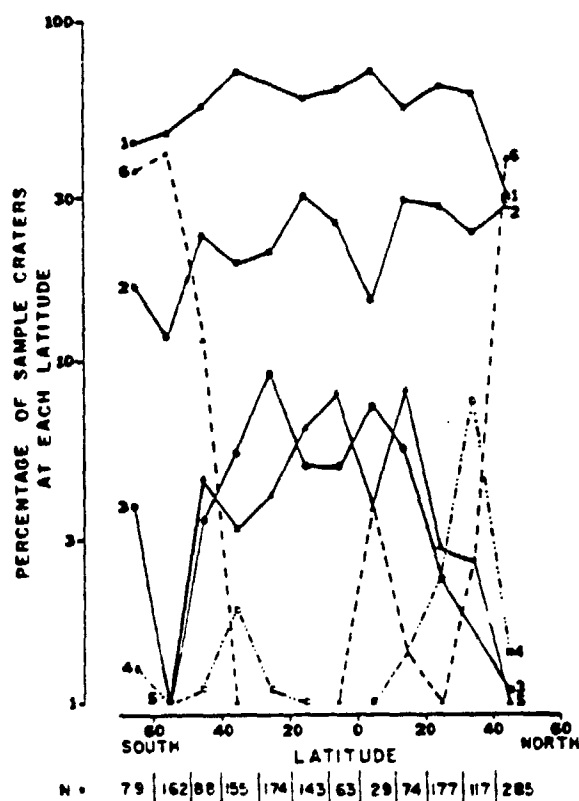
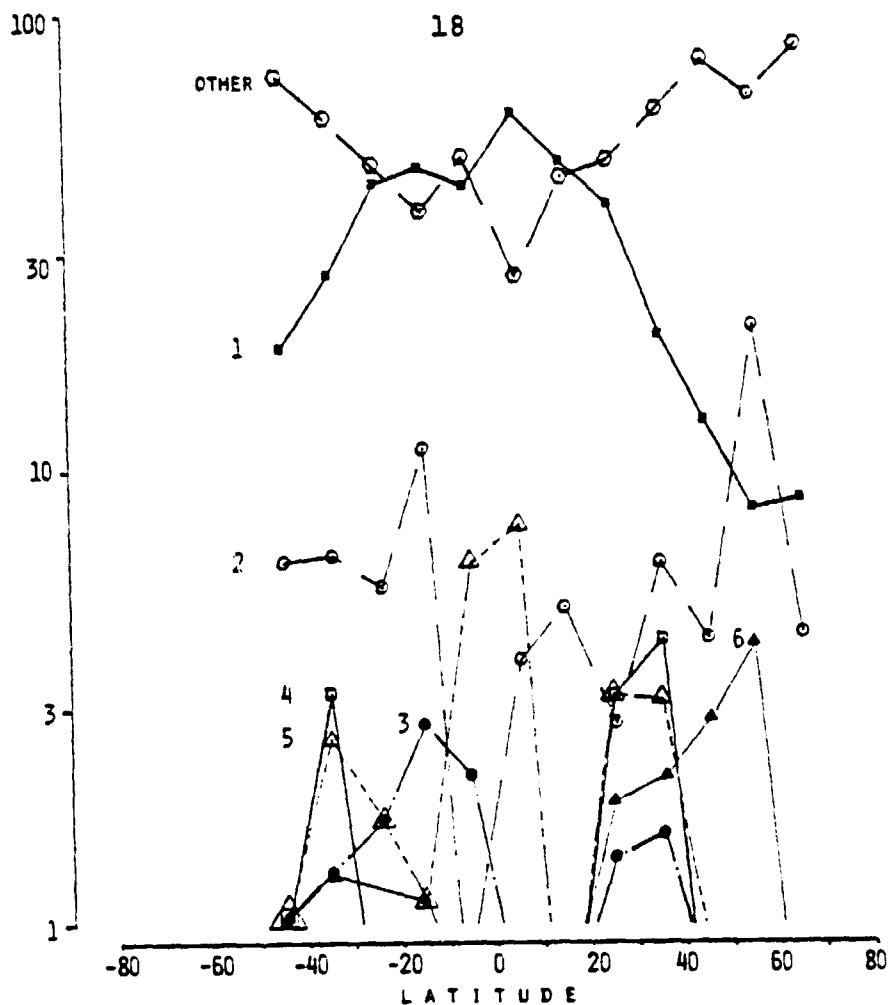


Fig. A7 From Mouginis-Mark, 1979.



N = 3 13 10 96 155 234 178 47 26 119 215 188 70 24 23 7

Fig. A8 Distribution with latitude in our test data of six classes of craters patterned after six types of Mouginis-Mark (1979). Compare with Figure A7. Other craters in our data set are also indicated.

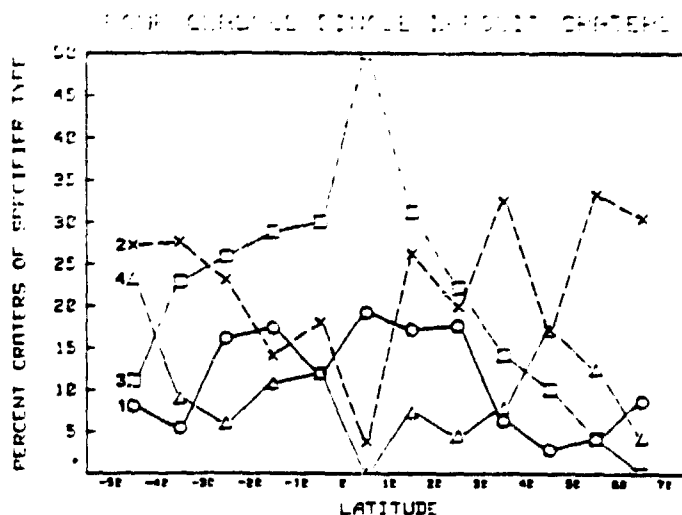
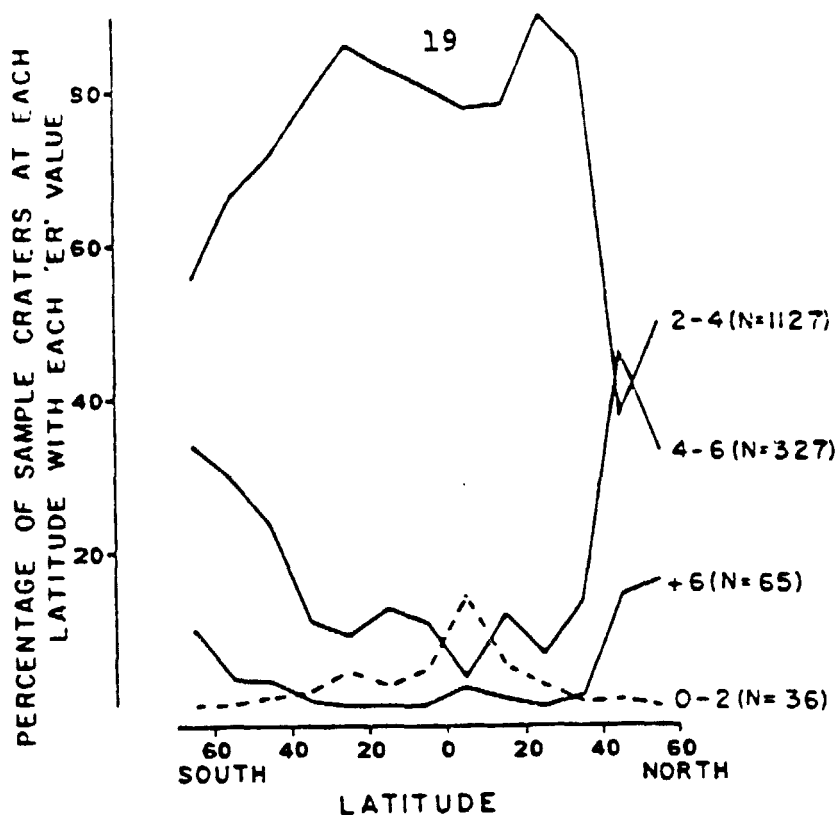


Fig. A9 Distribution with latitude of four classes of single ejecta deposit craters. Classes 1 and 3 deposits with marginal ridges seem concentrated in equatorial latitudes while Classes 2 and 4, with marginal scarps dominate at higher latitudes. See text for complete discussion.



| | | | | | | | | | | | | | |
|--------|----|-----|----|-----|-----|-----|----|----|----|-----|-----|-----|----|
| SAMPLE | 79 | 162 | 88 | 155 | 174 | 143 | 63 | 27 | 74 | 177 | 117 | 285 | 12 |
| SIZE | | | | | | | | | | | | | |

Variability of ejecta mobility with crater latitude. For each crater the maximum ejecta range from the center of the primary is normalized by the crater radius to give the ejecta range ratio *ER*. The four curves illustrate the incidence of craters with each *ER* value as a percentage of all craters in any 10° latitude bin. At least 30 craters are represented at each latitude; *N* is the number of craters at all latitudes with each *ER* value.

Fig. A10 From Mouginis-Mark (1979).

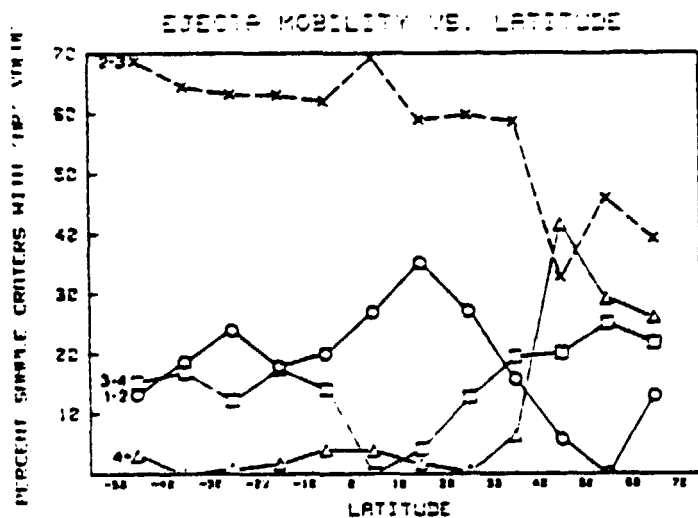


Fig. A11 Ejecta mobility versus latitude as seen in our test data. We detect an enhancement of ejecta range at high northern latitude as reported by Mouginis-Mark